# Appendix C
# Development and Implementation of NAVD 88

## C-1. General Background

This appendix provides technical guidance and implementation procedures for the conversion from the National Geodetic Vertical Datum of 1929 (NGVD 29) to the North American Vertical Datum of 1988 (NAVD 88). (This guidance was originally published as an Engineer Technical Letter in 1994 and is still generally applicable for projects not yet converted to NAVD 88. Note that some of the references are dated and network definitions have been modified by NOAA/NGS. The most recent guidance should be obtained from USACE and NOAA web sites listed at Appendix A).

*a*. The NAVD 88 is an updated vertical datum for North America that effectively covers Canada, Mexico, and the US. The new adjustment of the US National Vertical Control Network (NVCN) was authorized in 1978, and in 1982 the National Oceanic and Atmospheric Administration (NOAA) and Canada signed a Memorandum of Understanding (MOU) regarding the adoption of a common, international vertical control network called the NAVD 88.

*b.* The Federal Geodetic Control Subcommittee (FGCS) of the Federal Geographic Data Committee (FGDC) has adopted the new NAVD 88 datum. In addition, NAVD 88 was established in conjunction with the International Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data. This committee defined the IGLD 85, which was published for use in January 1992. IGLD 85 replaced IGLD 55.

## C-2. References

*a.* Water Resources Development Act of 1992 (WRDA 92), Section 224, Channel Depths and Dimensions.

*b.* EM 1110-2-1003 (*Hydrographic Surveying*).

*c.* Converting the National Flood Insurance Program to the North American Vertical Datum of 1988: Guidelines for Community Officials, Engineers, and Surveyors, FEMA Report No. FIA-20, June 1992.

*d.* Results of the General Adjustment of the North American Datum of 1988, American Congress on Surveying and Mapping Journal of Surveying and Land Information Systems, Vol. 52, No. 3, 1992, pp. 133-149.

*e.* American Congress on Surveying and Mapping Ad Hoc Committee Report on NAVD 88, Special ACSM Report, 1990.

## C-3. Discussion

*a.* NGVD 29 has been replaced by NAVD 88, an international datum adopted for use in Canada, the United States, and Mexico. NAVD 88 was established to resolve problems and discrepancies in NGVD 29. The adjustment of NAVD 88 was completed in June 1991 by the National Geodetic Survey (NGS), an agency of the Department of Commerce, National Oceanic and Atmospheric Administration (NOAA). NAVD 88 was constrained by holding fixed the height of a single primary tidal benchmark (BM) at Father's Point/Rimouski, Québec, Canada, and performing a minimally constrained general adjustment of US-Canadian-Mexican leveling observations. The result of this adjustment is newly published NAVD 88 elevation values for benchmarks in the NGS inventory. Most Third Order BMs, including those of other Federal, state and local government agencies, were not included in the NAVD 88 adjustment.

*b.* The Federal Geodetic Control Subcommittee (FGCS) of the Federal Geographic Data Committee (FGDC) has affirmed that NAVD 88 shall be the official vertical reference datum for the US. The FGDC has prescribed that all surveying and mapping activities performed or financed by the Federal Government make every effort to begin an orderly transition to NAVD 88, where practicable and feasible.

*c.* Both tidal and non-tidal low water reference planes and datums are affected by the change to NAVD 88. The datum for the Great Lakes is now the International Great Lakes Datum of 1985 (IGLD 85). Unlike the prior datum (IGLD 55), IGLD 85 has been directly referenced to NAVD 88 and originates at the same point as NAVD 88. Elevations of reference points/datums along the various inland waterway systems will also be impacted by the change in datums.

*d.* The transition to NAVD 88 may have considerable impact on Corps projects, including maps, drawings, and other spatial data products representing those projects. However, once completed, the transition will result in a more accurate vertical reference datum that has removed leveling errors, accounts for subsidence, and other changes in elevation.

*e.* The computer program VERTCON can be used to make approximate conversions between NGVD 29 and NAVD 88. This program was developed by NGS and during the later part of FY94 has been incorporated into the USACE program CORPSCON. VERTCON conversions are intended for general small-scale mapping uses -- VERTCON should not be used for converting benchmark elevations used for site plan design or construction applications.

*f.* The conversion to NAVD 88 should be accomplished on a project-by-project basis. The relationship of all project datums to both NGVD 29 and NAVD 88 will be clearly noted on all drawings, charts, maps, and elevation data files.

*g.* In accordance with Section 24 of WRDA 92, when elevations are referred to a tidal reference plane in coastal waters of the US, Mean Lower Low Water (MLLW) shall be used as the vertical datum--see Appendix B in this manual. Tidal BMs should be tied to NAVD 88 instead of NGVD 29 where NAVD 88 data is available. Tidal datums shall be established in accordance with the procedures outlined in EM 1110-2-1003 (*Hydrographic Surveying*).

*h.* Other hydraulic-based reference planes established by USACE for the various inland waterways, reservoirs, and pools between control structures should continue to be used for consistency; however, they should also be connected with the NAVD 88 where practicable and feasible.

*i.* In project areas where local municipal or sanitary jurisdictions have established their own vertical reference planes, every attempt should be made to obtain the relationship between that local datum and NGVD 29 and/or NAVD 88; and clearly note this relationship on all drawings, charts, maps, and elevation data files.

## C-4. The National Vertical Control Network (NVCN): NGVD 29 and NAVD 88

*a.* The NVCN consists of a hierarchy of interrelated nets that span the United States. Before the adoption of NAVD 88, benchmark elevations of the NVCN were published as orthometric heights referenced to NGVD 29. NGVD 29 was established by the United States Coast and Geodetic Survey

(USC&GS) 1929 General Adjustment. NGVD 29 was established by constraining the combined US and Canadian first order leveling nets to conform to Mean Sea Level (MSL) as determined at 26 long-term tidal gage stations that were spaced along the east and west coast of North American and along the Gulf of Mexico, with 21 stations in the US and 5 stations in Canada.

*b.* Local MSL is a vertical datum of reference that is based upon the observations from one or more tidal gaging stations. NGVD 29 was based upon the assumption that local MSL at those 21 tidal stations in the US and 5 tidal stations in Canada equaled 0.0 foot on NGVD 29. The value of MSL as measured over the Metonic cycle of 19 years shows that this assumption is not entirely valid and that MSL varies from station to station.

*c*. The NGVD 29 was originally named the Mean Sea Level Datum of 1929. It was known at the time that because of the variation of ocean currents, prevailing winds, barometric pressures and other physical causes, the MSL determinations at the tide gages would not define a single equipotential surface. The name of the datum was changed from the Mean Sea Level Datum to the NGVD 29 in 1973 to eliminate the reference to sea level in the title. This was a change in name only--the definition of the datum established in 1929 was not changed. Since NGVD 29 was established, it has become obvious that the geoid based upon local mean tidal observations would change with each measurement cycle. Estimating the geoid based upon the constantly changing tides does not provide the most stable estimate of the shape of the geoid, or the basic shape of the earth.

*d.* The datum for NAVD 88 is based upon the mass or density of the Earth instead of the varying heights of the seas. Measurements in the acceleration of gravity are made at observation points in the network and only one datum point, at Pointe-au-Pere/Rimouski, Québec, Canada, is used. The vertical reference surface is therefore defined by the surface on which the gravity values are equal to the control point value. Although the international cooperation between the United States and Canada greatly strengthened the 1929 network, Canada did not adopt the 1929 vertical datum. The NGVD 29 was strictly a national datum. NAVD 88 is an international vertical datum for the US, Canada, and Mexico.

## C-5. Distinction between Orthometric and Dynamic Heights

*a.* There are several different reference elevation systems used by the surveying and mapping community. Two of these height systems are relevant to IGLD 85: orthometric heights and dynamic heights. Geopotential numbers relate these two systems to each other. The geopotential number (C) of a BM is the difference in potential measured from the reference geopotential surface to the equipotential surface passing through the survey mark. In other words, it is the amount of work required to raise a unit mass of 1 kg against gravity through the orthometric height to the mark. Geopotential differences are differences in potential which indicate hydraulic head. The orthometric height of a mark is the distance from the reference surface to the mark, measured along the line perpendicular to every equipotential surface in between. A series of equipotential surfaces can be used to represent the gravity field. One of these surfaces is specified as the reference system from which orthometric heights are measured. These surfaces defined by the gravity field are not parallel surfaces because of the rotation of the earth and gravity anomalies in the gravity field. Two points, therefore, could have the same potential but may have two different orthometric heights. The value of orthometric height at a point depends on all the equipotential surfaces beneath that point.

*b.* The orthometric height ($H$) and the geopotential number ($C$) are related through the following equation:

$$C = G \cdot H \qquad \text{(Eq C-1)}$$

where *G* is the gravity value estimated for a particular system. Height systems are called different names depending on the gravity value (*G*) selected. When *G* is computed using the Helmert height reduction formula that is used for NAVD 88, the heights are called Helmert Orthometric Heights. When *G* is computed using the International Formula for Normal Gravity, the heights are called Normal Orthometric Heights. When *G* is equal to normal gravity at 45 deg latitude, the heights are called Normal Dynamic Heights. It should be noted that dynamic heights are just geopotential numbers scaled by a constant, using normal gravity at 45 deg latitude equal to 980.6199 gals. Therefore, dynamic heights are also an estimate of hydraulic head. In other words, two points that have the same geopotential number will have the same dynamic height.

*c.* IGLD 55 is a normal dynamic height system that used a computed value of gravity based on the International Formula for Normal Gravity. Today, there is sufficient observed gravity data available to estimate "true" geopotential differences instead of "normal" geopotential differences. The "true" geopotential differences, which were used in developing IGLD 85 and NAVD 88, will more accurately estimate hydraulic head.

## C-6. Problems with NGVD 29 and Why a New Datum needed to be Established

*a.* Approximately 625,000 km of leveling have been added to the National Geodetic Reference System (NGRS) since the 1929 adjustment. Each new line has been adjusted to the network. The new leveling data uncovered some problems in NGVD 29. Through the years, the agreement between the new leveling and the network BM elevations slowly grew worse. An investigation of NGVD 29 general adjustment results indicates that large residuals were distributed in some areas of the country during that adjustment. For example, the accumulated 1929 adjustment correction along a 3000 km east-west leveling route from Crookston, Minnesota, to Seattle, Washington is a delta of 89 centimeters (cm).

*b.* Inconsistencies in NGVD 29 have increased over the years. This increase is a function of factors such as:

(1) Many BMs were affected by unknown vertical movement due to earthquake activity, post-glacial rebound, and ground subsidence.

(2) Numerous BMs were disturbed or destroyed by highway maintenance, building, and other construction.

(3) New leveling became more accurate because of better instruments, procedures, and improved computations. It was decided in 1977 that the high accuracy achieved by the new leveling was being lost when forced to fit the 1929 network, and plans were made to begin developing a new national vertical network.

*c.* These inconsistencies have not always been apparent to the user since NGS has periodically readjusted large portions of the NVCN and spread these large residuals over large areas. Eventually, however, there would be a large number of areas in which surveyors would not be able to check their work using NGVD 29. NAVD 88 is specifically designed to remove the inconsistencies and distortions such as those found in the NGVD 29. NGS has held off incorporating approximately 40,000 km of newer leveling data for these reasons. These data were incorporated into the NAVD 88.

## C-7. Selection of the Adjustment Method for NAVD 88

*a.* The FGCS created a Vertical Subcommittee in 1989 to study the impact of the NAVD 88 on the programs of member agencies and to recommend a datum definition. Several different datum definitions for NAVD 88 were studied by the subcommittee and the three options below were selected for final consideration:

(1) Fix the elevation or mean sea level at a single point.

(2) Fix mean sea level at four tide gages located at the network corners.

(3) Fix the NGVD 29 elevations at 18 existing, well-scattered BMs.

*b.* Two options were considered for the establishment of the vertical datum: (1) tidal epoch or (2) a minimally constrained adjustment. The tidal epoch option required that the adjustment hold MSL fixed at all appropriate primary tide stations and use the latest available tidal epoch. This definition is actually the same as NGVD 29, but used the latest data available. The other option used a minimally constrained adjustment holding local MSL fixed at one primary tide station and adjusting all leveling data to it. This second option would maintain the integrity of the leveling data but would also create the greatest deviation from the presently published data.

*c.* Research was done by NGS to determine which option would be the best choice. To assist in the NAVD 88 datum definition decision, several adjustments were performed using different constraints. The results obtained from several trial adjustments indicate that no matter which datum definition scenario is chosen for NAVD 88, including a minimally constrained adjustment that changes in absolute heights of as much as 75 to 100 cm would exist between NGVD 29 and NAVD 88.

*d.* In addition to the NGS research, agencies and appropriate bodies were queried to determine which option would be their preference and to ask for recommendations. The FGCS and the American Congress on Surveying and Mapping (ACSM) established committees to investigate the impact of NAVD 88 on their members' activities and the activities of others in the community. Members of these committees were requested to provide documentation on the affects that the readjustment would have on their user populations and to include specific examples describing the real impact of a new vertical datum on their products. USACE was included in the questionnaire survey.

*e.* As a preliminary measure, both committees drafted recommendations for NAVD 88 and specified that NGS should:

(1) Perform minimally-constrained least squares adjustment of the data for NAVD 88.

(2) Shift the datum vertically to minimize recompilation of National Mapping Products.

(3) Develop computer transformation software to convert between NGVD 29 and NAVD 88. ("VERTCON").

(4) Develop national and/or regional geoid models to ensure GPS height differences meet at least 2nd Order, Class II FGCS precise geodetic leveling standards for accuracy.

*f.* Results indicated that the tidal epoch option would minimize the magnitude of the changes from NGVD 29 to NAVD 88 and thus possibly allow direct comparison of present hydrographic survey elevations with the proposed new NAVD 88 elevations. The smaller change between elevations would cause less confusion and concern over flow heights, and the like. Regardless of the datum definition selected, large differences would exist between the NAVD 88 and the NGVD 29 heights. It should be noted that the NAVD 88 heights are better estimates of orthometric heights than the NGVD 29 heights. Better estimates of orthometric heights will become more critical in the future as surveying techniques continues to become more sophisticated and more accurate. The improved accuracy of geoid height determinations using GPS data requires the best estimate of true orthometric heights. Many cartographers want heights on their maps based on the best estimate of true orthometric heights.

## C-8. The NAVD 88 Adjustment

*a.* The NAVD 88 adjustment is the culmination of over ten years of work. This effort has included: establishing about 100,000 km of trunk line leveling to reinforce weak areas in the network; modernizing the vast amount of leveling observation and description data that has been collected for over a century; performing adjustments of sections of the network to verify the quality of the observation data; informing the public users of the network of the pending change and determining the impact on the nation's engineering activities. After the datum definition was selected to be a minimally constrained adjustment, the final task of this effort was to perform the least squares adjustment of the whole network.

*b.* The general adjustment of NAVD 88 was completed in June 1991. The primary network consists of 200 loops containing 909 junction BMs. The network connects to 57 primary tidal stations, which are part of the National Primary Tidal Network, and 55 international water-level stations along the Great Lakes. In addition, 28 border connections were made to the Canadian vertical control network and 13 to the Mexican vertical control network. Third Order BMs of other agencies (e.g., USACE) were not included in this adjustment. The 500,000 BMs established by the USGS were also not placed in computer readable form and therefore will not have NAVD 88 heights. In addition, USACE commands have established thousands of BMs that will not have NAVD 88 heights.

*c.* A particular concern for the developers of the NAVD 88 was how to resolve the many issues associated with the National Mapping Program (NMP) of USGS and the National Map Accuracy Standard (NMAS). The NMP includes more than 83,000 different map products of which over 7 million copies are distributed annually. Almost all of these products contain elevation information as contours and spot elevations on maps or as elevation arrays in Digital Elevation Models. Changing these products, both graphical and digital, to the NAVD 88 will be a massive and costly undertaking and will require a decade or more to complete.

*d.* The new leveling data have additional corrections applied for refraction and rod correction and are adjusted in geopotential units rather than the orthometric system used in the past. The datum definition is the most scientifically acceptable of all the definitions considered and is the most natural because it is based on an undisturbed representation of the Earth's gravity field. It is the most suitable for the geoid height computations needed for the reduction of GPS ellipsoidal heights. The main disadvantage is the differences with MSL on the west coast. At Seattle, a person standing on the zero elevation contour (NAVD 88) will barely have their head above water at mid-tide.

*e.* Preliminary analysis indicates that the overall differences between orthometric heights referred to NAVD 88 and to the NGVD 29 range from approximately -40 cm to +150 cm. Most surveying applications should not be significantly affected because the changes in relative height between adjacent BMs in most geotechnically stable areas should be less than 1 cm. In many geotechnically stable areas, a single bias factor describing the difference between NGVD 29 and NAVD 88 can be estimated and used for most mapping applications. This was a significant consideration for assessing the impact on the national mapping products. The absolute height values will change much more, but this should not be the surveyor's biggest concern, since he/she should be concerned with ensuring that all height values of BMs are referenced to the same vertical datum. The overall differences between dynamic heights referred to the IGLD 85 and to IGLD 55 will range from approximately 1 to 40 cm.

## C-9. International Great Lakes Datum of 1955 (IGLD 55)

*a.* IGLD 55 is a datum common to the United States and Canada and is defined by international agreement. Before the establishment and adoption of the IGLD 55, the differences in elevation between the lakes had been determined but had not been connected to sea level and lake level data published from the United States and Canada did not match for the same lakes and rivers. The IGLD 55 was an international cooperative effort between the those two countries, the result of which was that the Great Lakes-St. Lawrence River system was then covered by a single uniform vertical control network. The IGLD 55 is different and separate from the NGVD 29.

*b.* IGLD 55 is by definition a hydraulic (i.e., dynamic) datum. The reference zero for IGLD 55 is based on mean water level surface at Father's Point (Pointe-au-Pere), Québec, Canada. Holding this point fixed determined the IGLD 55 datum. A procedure termed a "water level transfer" has been used to establish a local vertical datum on each of the Great Lakes. Research has concluded that the water level transfer technique was concluded to be at least as accurate as First Order, Class I geodetic leveling. The remaining lakes were incorporated using a combination of level lines and water level transfers. Adjusted elevations on the IGLD55 are referenced using the dynamic number system. The dynamic value of a benchmark is not a true linear elevation, but a serial number given to the level surface on which the mark lies. Dynamic elevations were adopted for the IGLD 55 primarily because they provide a means by which the geopotential hydraulic head can be measured more accurately between two points.

*c.* The earth's crust experiences movements around the entire Great Lakes and St. Lawrence River area. Therefore, the vertical reference datum for this area must be vertically readjusted every 25 to 30 years. This crustal movement is called "isostatic rebound," which is the gradual rising of the earth rebounding from the weight of the glaciers during the last glacial age. When IGLD 55 was created, it was known that readjustment would be necessary due to the effects of isostatic rebound. Crustal movement is not uniform across the Great Lakes basin and causes benchmarks to shift not only with respect to each other, but also with respect to the initial reference point. Subsidence and other local effects can cause benchmarks to shift as well.

## C-10. International Great Lakes Datum of 1985 (IGLD 85)

*a.* The Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data revised the IGLD 55 datum and established IGLD 85. This committee has input to the international management of the Great Lakes-St. Lawrence River system. Representatives from the US and Canada are members on this committee. The efforts of the Coordinating Committee to revise IGLD 55 and establish IGLD 85 were coordinated with the efforts to establish the new common international vertical datum for the US, Canada and Mexico, NAVD 88.

*b.* The IGLD 85 is the current vertical control reference system in the Great Lakes Basin. The IGLD 55 was the vertical control reference system for this area until the publication of the IGLD 85 in January 1992. Originally, an IGLD 80 had been planned, but the project was extended. The epoch that was actually used to determine the mean water level for the new datum was from 1983-1988, of which the mean year is 1985. The reference zero point for IGLD 85 is located at benchmark #1250G, located at Rimouski, Québec. This benchmark has an IGLD85 elevation of 6.723 meters and IGLD 55 elevation of 6.263 meters. IGLD 85 increases the number and accuracy of benchmarks in the Great Lakes area. Corps districts were targeted to have converted over to IGLD 85 by January of 1993. This cannot be practically done until NOAA publishes complete IGLD 85 BM data for the area. IGLD 85 data is available for the gages, but the spacing of the gages is not dense enough to support conversion of local project control.

*c*. Agencies in the US and Canada will use IGLD 85. The National Oceanic Service (NOS) and the Canadian Hydrographic Service (CHS) began reporting water levels referenced to IGLD 85 upon its implementation in January 1992. For a period of time, conversion factors for both IGLD 55 and IGLD 85 water level data will be provided by NOAA/NOS Great Lakes Section and CHS. The monthly water level bulletins published by USACE and CHS will reflect this information.

*d.* IGLD 85 will not change water levels established for federal flood insurance programs in the US. These levels will be referred to NAVD 88. Elevations common to both NAVD 88 and IGLD 85 are available from NOAA. Lake level outflows also will not be affected by the datum change to IGLD 85. As benchmark information becomes available, navigation, construction, and other improvement work on the Great Lakes should be referred to IGLD 85. Either datum is acceptable until the benchmark data is available for the respective USACE District or project area. Drawings shall include a note for the vertical IGLD datum in use to avoid blunders. USACE permit applications will still be referenced to the Ordinary High Water Mark (OHWM) as defined under Section 10 of the Rivers and Harbors Act. As benchmark information becomes available, new applications should reference IGLD 85.

## C-11. NAVD 88 and IGLD 85

*a*. The specific needs of the Great Lakes system were taken into account while the decision was being made about how NAVD 88 was to be established. Analyses of data in the Great Lakes Basin was used to determine the effects of the datum constraint, magnitudes of height changes from the IGLD 55, deficiencies in the network design, selection of water-level station pairs to be used to generate zero geopotential difference observations, and additional re-leveling requirements. This coordination provided a check on the accuracy of the work and established a conversion between the IGLD 85 and NAVD 88.

*b*. Elevations referenced to NGVD 29 are unacceptable for use in resolving the involved problems of the Great Lakes System. The reference zero for NGVD 29 is not located within the Great Lakes system and orthometric elevations are not sufficient for use with large bodies of water such as the Great Lakes. The dynamics of large bodies of water are not modeled well by considering them as single equipotential surfaces. Other forces such as gravity must be considered. For example, water level measurements obtained at both ends of the Lake and connected to the NGVD 29 would show some magnitude of a permanently northerly slope.

*c*. The general adjustment of the NAVD 88 and IGLD 85 is one and the same. A minimum constraint adjustment of Canadian-Mexican-US leveling observations was performed holding fixed the height of the primary tidal BM, referred to the new IGLD 85 local mean sea level height value, at Father's Point/Rimouski, Québec, Canada. This constraint satisfies the requirements of shifting the datum vertically to minimize the impact of NAVD 88 on USGS mapping products, as well as provides the datum point desired by the IGLD Coordinating Committee for IGLD 85. The only difference between IGLD 85 and NAVD 88 is that IGLD 85 BM values are given in dynamic height units and NAVD 88 values are given in Helmert orthometric height units. The geopotential numbers of BMs are the same in both systems.

*d*. Geopotential numbers from the general adjustment of NAVD 88 were used to compute IGLD 85 dynamic heights. They will provide the best estimate of hydraulic head. If secondary gage data are placed in computer readable form, they will also be incorporated into NAVD 88 and IGLD 85. NGS will publish NAVD 88 heights and provide, upon special request, geopotential numbers for all BMs included in NAVD 88.

*e*. The use of GPS data and a high-resolution geoid model to estimate accurate GPS-derived orthometric heights will be a continuing part of the implementation of NAVD 88 and IGLD 85. It is important that users initiate a project to convert their products to NAVD 88 and IGLD 85. The conversion process is not a difficult task, but will require time and resources. Other local reference planes have been established by local jurisdictions and these can be referenced to either IGLD 85 or NAVD 88.

## C-12. Low Water Reference Planes (LWRP)

*a*. On the Mississippi River between the mouths of the Missouri and the Ohio Rivers (the Middle Mississippi River), depths and improvements are referenced to a LWRP. No specific LWRP year is used for the Middle Mississippi north of Cairo, IL. Below Cairo, IL, depths and improvements along the Lower Mississippi River are referenced to the 1974 LWRP. This is also a hydraulic reference plane, established from long-term observations of the river's stage, discharge rates, and flow duration periods. The low water profile was developed about the 97-percent flow duration line. The elevation of the 1974 LWRP drops gradually throughout the course of the Mississippi, however, some anomalies in the profile are present in places (particularly in areas containing rock bottoms or groins/weirs). The gradient is approximately 0.5 feet per river mile. The ever-changing river bottom will influence the 1974 LWRP. Changes in the stage-discharge relationship will influence the theoretical flow line for the 1974 LWRP.

*b*. Construction and improvements along the lower river are performed relative to the 1974 LWRP at a particular point. Differences in 1974 LWRP elevations between successive points along the river are determined from simultaneous staff readings and are referenced to benchmarks along the bank. The 1974 LWRP slope gradients between any two points must be corrected by linear interpolation of the profile. Thus, over a typical 1-mile section of river with a 0.5-foot gradient, each 1000-foot C/C river cross section will have a different 1974 LWRP correction, each dropping successively at approximately 0.1-foot increments.

*c*. Where practicable and feasible, NAVD 88 should be used as the common reference plane from which 1974 LWRP elevations are measured. The relationship of all project datums to both NGVD 29 and NAVD 88 should be clearly noted on all drawings, charts, maps, and elevation data files. All initial surveys should be referenced to both NAVD 88 and NGVD 29. If this is not feasible, then NGVD 29 should be used as the common reference plane from which 1974 LWRP elevations are measured until the move to NAVD 88 can be accomplished. Differences between the 1974 LWRP and NGVD 29 are published for the reference benchmarks used to control surveys and construction activities. In some districts, surveys are performed directly on NGVD 29 without regard to the 1974 LWRP profile (i.e., elevations above NGVD 29 are plotted rather than depths below 1974 LWRP). The 1974 LWRP depths are then contoured from the plotted NGVD 29 elevations, with the 1974 LWRP profile gradients applied during the contouring process. If a survey is conducted over a given reach of the river, the 1974 LWRP-NAVD 88 and/or the 1974 LWRP-NGVD 29 conversion must be interpolated based on the slope profile over that reach.

*d*. Controlled portions of the Upper Mississippi are referred to pool levels between the controlling structures. Although a variety of reference datums are used on other controlled river systems or impoundment reservoirs, most are hydraulically based and relate to some statistical pool level (e.g., "normal pool level," "flat pool level," "minimum regulated pool level ," etc.).

*e*. On the Mississippi River above Melvin Price Locks and Dam at Alton, IL, to Lock and Dam No. 22 at Saverton, MO, the reference used is related to the minimum regulated pool elevation. These pools are regulated referenced to a "hinge point." The pools are drawn down when the river's flow will provide adequate navigation depths naturally. When the flows are reduced to low volumes, the pools are reestablished and are essentially level. The depths and improvements along this reach of the Mississippi River are referenced to the "minimum regulated pool" elevations.

*f.* On the Mississippi River above Lock and Dam No. 22 at Saverton, MO, to St. Paul, MN, a "flat pool level" reference is used, and soundings are shown as "depth below flat pool." The flat pool is the authorized elevation of the navigation project and can be referenced to any number of local datums. Most commonly, this level is referenced to the mean sea level (MSL) datum of 1912, the general adjustment which preceded 1929. Conversions between MSL 1912 and NGVD 29 are available. The Illinois Waterway pool elevations are referred to NGVD 29, however, relationships to numerous other datums are also made.

*g.* Vertical clearances (bridges, transmission lines, etc.) are usually measured relative to high and low waters of record, or relative to full pool elevations. Shore lines shown on river drawings and navigation maps may be referenced to a low water datum (i.e., 1974 LWRP). On the Mississippi River above Lock and Dam No. 22 at Saverton, MO, the plotted shoreline is referenced to full pool stage at dams with discharges equaled or exceeded 90 percent of the time. Given the variety of reference levels, special care must be taken to properly identify the nature and source of all vertical reference datums used on a project. The datum notes should include and clearly depict the relationship to NAVD 88.